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Mitigating operational risks and enhancing machine performance through total productive maintenance and OEE: A case study on packaging equipment

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Abstract

This study evaluates the effectiveness of a laser marking machine in an instant noodle packaging line using a Total Productive Maintenance (TPM) framework and Overall Equipment Effectiveness (OEE) metrics over a 12-month period. A mixed-method design combined direct observation, semi-structured interviews with operators and technicians, and a literature review to assess availability, performance efficiency, and quality rate. The machine achieved excellent availability, averaging 98.95%, reflecting the impact of preventive maintenance in reducing unplanned downtime. Performance efficiency varied substantially, ranging from 59.13% to 93.27%, indicating significant headroom for productivity improvement through cycle-time stabilization and minor-stoppage reduction. The quality rate averaged 89.21% and remained relatively stable, though still short of ideal benchmarks, suggesting the need for tighter in-process quality control. The monthly OEE peaked at 84.77% in April, approaching the JIPM benchmark of 85%, while the period average was 60.38%, underscoring the need for sustained improvement initiatives. Among the three components, performance efficiency exerted the greatest influence on OEE due to its high variability across months.

Keywords:

Total productive maintenance, overall equipment effectiveness, laser marking, machine effectiveness, maintenance management

1 Introduction

In today's highly competitive industrial landscape, machine efficiency and effectiveness are critical to sustaining production and cost competitiveness. Companies are compelled to deliver high- quality products in shorter cycle times and at minimal cost, making optimal use of equipment and production assets essential rather than optional. Operational efficiency encompasses not only throughput but also resource utilization, minimized downtime, and conformance to specifications without generating defects, while operational effectiveness emphasizes consistently meeting targets across availability, performance, and quality dimensions. Data-driven strategies such as predictive maintenance, automation, and sensor- based monitoring, supported by operator training and continuous condition supervision, can raise productivity, extend equipment life, and reduce operating costs. Industry exemplars have shown that integrating IoT- enabled monitoring and analytics enables early detection of wear or malfunction, scheduling maintenance before failures, cutting stoppages, improving quality, and optimizing maintenance resources [1]. Global competition is becoming increasingly intense, compelling every company to produce high-quality products within shorter production times and at the lowest possible cost [2]. Consequently, an industry's success in maintaining its competitiveness largely depends on its ability to optimize the use of available machinery and production equipment. Efficient and effective operations are no longer optional in today's dynamic industrial environment; they are essential for sustaining a competitive advantage [3][4].

Operational efficiency concerns not only production speed but also optimal resource utilization, minimal downtime, and the machine's ability to operate within specifications without producing defective products. Operational effectiveness refers to the extent to which machines consistently meet production targets, accounting for factors such as availability, performance, and output quality. The combination of efficiency and effectiveness helps evaluate the performance of production systems [5].

To achieve optimal efficiency and effectiveness, companies must adopt data- and technology-driven strategies, such as predictive maintenance, automation, and sensor-based monitoring [6]. Operator training and continuous machine condition supervision are critical for ensuring process stability. With these strategic measures, companies can increase productivity, extend machine lifespan, and significantly reduce operational costs [7][8]. The approach to machine management illustrates how integrating technology with operational strategy can significantly enhance industrial performance and maintain a competitive edge [9].

One of the most effective approaches to improving machine performance in industrial environments is Total Productive Maintenance (TPM). TPM is a maintenance strategy aimed at achieving maximum equipment efficiency through a comprehensive and systematic approach[10][11]. The methodology emphasizes the maintenance team's role and involves all organizational levels from operators to top management in the ongoing effort to maintain and improve equipment conditions. TPM strives to create a reliable, safe, and highly efficient production system with its core principles of zero breakdowns, zero defects, and zero accidents[12]. TPM places significant importance on empowering operators through autonomous maintenance, which involves enabling them to conduct routine inspections, perform minor maintenance tasks, and detect early signs of potential equipment failure. This approach reduces dependence on maintenance technicians while fostering a sense of ownership and responsibility among operators[13]. TPM implementation is typically structured around eight foundational pillars, including focused improvement, planned maintenance, quality maintenance, and continuous training. Consistent application of these pillars has been shown to reduce equipment downtime, improve product quality, and lower production costs effectively[14].

In practice, TPM is often integrated with performance measurement tools such as Overall Equipment Effectiveness (OEE) to evaluate its implementation outcomes [15]. OEE assesses three key dimensions: availability, performance, and quality, which together reflect the overall utilization and effectiveness of equipment. An increase in OEE values is generally seen as an indicator of successful TPM implementation. As a result, many manufacturing companies adopt TPM as a core strategy for improving productivity and operational efficiency, particularly in today's highly competitive and quality-oriented industrial landscape[16][17].

The Laser Marking machine, as a vital component of the instant noodle packaging process, requires high reliability and performance. Failure or a decrease in the effectiveness of this machine can significantly impact the overall production process. Therefore, measuring and evaluating machine performance using the OEE parameter is essential for identifying areas for improvement [18].

TPM is a proven, systematic approach to maximizing equipment efficiency through organization- wide involvement, emphasizing zero breakdowns, zero defects, and zero accidents. TPM empowers operators through autonomous maintenance for routine inspections, minor tasks, and early anomaly detection, reducing reliance on technicians and fostering ownership at the frontline. Its eight foundational pillars, including focused improvement, planned maintenance, quality maintenance, and continuous training, have been shown to reduce downtime, improve quality, and lower costs, and are often paired with OEE to quantify availability, performance, and quality outcomes over time. In the instant noodle packaging process, the laser marking machine is a critical station whose shortfalls can cascade across the line, making OEE- based measurement vital for pinpointing improvement priorities. This study provides a 12- month data set, maps six significant losses to TPM pillars, and offers a targeted improvement roadmap for laser- marking operations at an Indonesian facility.

2 Research methodology

2.1 Data collection methods

Data for this research were obtained through multiple complementary approaches to ensure comprehensive coverage of the production system. Primary data were gathered via direct observation of the production operations and semi-structured interviews with relevant personnel involved in machine operation and maintenance. A literature review supplemented these qualitative data, providing theoretical grounding and contextual support for the analysis. The working system of the instant noodle packaging machine was systematically decomposed into its central functional units, including the infeed conveyor, etiquette roll, scanner head, electronic control unit, and mechanical adjustment system. This decomposition was conducted using functional mapping and structural breakdown techniques to identify and capture factors influencing equipment Availability (AV), Performance Efficiency (PE), and quality rate within the OEE framework. Subsequently, the OEE analysis followed standardized stages that included computing AV, PE, and quality rate, culminating in the calculation of the composite OEE. The calculations utilized twelve months of operational data comprising working hours, downtime, production output, and defect records obtained from production and maintenance reports [19][20].

2.2 System, unit, and component identification

The initial step in implementing TPM and conducting an OEE assessment is identifying the system, its functional units, and their constituent components. In the instant noodle packaging process, the laser marking machine comprises several integrated primary units that work together to ensure accurate and efficient product labeling. These include the infeed conveyor unit, the etiquette roll, the scanner head unit, the electronic control unit, and the mechanical system responsible for work-position adjustment. The identification process employed functional mapping and machine structure breakdown methods to document all relevant elements that potentially influence availability, performance, and quality in OEE evaluation [21][22]. Through this detailed identification, the study ensures that all operational and structural aspects of the equipment are accounted for in subsequent performance analysis.

2.3 Data management and analysis phase

The data management and analysis phase encompassed a systematic sequence of calculations to quantify equipment effectiveness using key performance indicators. The analysis involved four primary stages: (1) calculation of AV, (2) computation of PE, (3) determination of the Rate of Quality (RQ), and (4) derivation of the composite OEE [23]. The dataset used in these calculations included machine working hours, downtime durations, total production quantities, and defective product counts, spanning a continuous 12-month operational period. This structured analytical process provided a comprehensive understanding of how equipment performance, reliability, and quality collectively influence the packaging system's overall productivity.

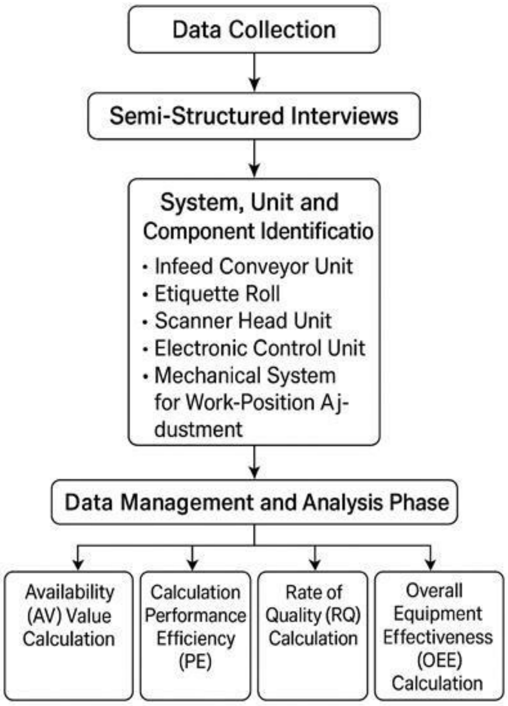

Fig. 1. Research flow

The Fig. 1 illustrates the research methodology applied in the study of the effectiveness of the instant noodle packaging machine. The research process begins with data collection through direct observation, semi-structured interviews, and a literature review to establish a strong theoretical foundation. This is followed by system, unit, and component identification using functional mapping and structural breakdown approaches, encompassing the infeed conveyor unit, etiquette roll, scanner head, electronic control system, and mechanical work-position adjustment system.

The next phase is data management and analysis, which involves calculating AV, PE, and RQ to determine the composite OEE. Throughout these stages, the research aims to identify the factors affecting machine effectiveness and to provide a foundation for decision-making to improve production equipment performance.

3 Results and discussion

3.1 AV analysis

AV remained very high throughout the study, averaging 98.95%, with monthly values ranging from approximately 98.41% to 99.28%, indicating low downtime relative to planned loading and effective preventive maintenance. PE fluctuated markedly between 59.13% and 93.27%, with April representing a best- practice month and September–October indicating constraints such as minor stoppages, adjustments, setup, or scheduling inefficiencies that limited capacity utilization. The quality rate ranged from 84.10% to 93.56%, averaging 89.21%, suggesting relatively stable conformance, with room for improvement through in-process controls, operator training, SPC tools, and calibration discipline. Composite OEE varied from 51.56% to 84.77%, peaking below but near the 85% Japan Institute of Plant Maintenance (JIPM) benchmark, with PE emerging as the primary lever for sustained gains, given its month- to- month volatility. A six-significant-losses perspective indicated performance- related losses, idling/minor stoppages, and speed loss as dominant, validating the focus on sensor alignment, conveyor speed tuning, and operator- led autonomous maintenance to reduce micro- downtime and stabilize output. The AV calculation results for each month are shown in Table 1.

High-value AV indicates that machine downtime is low relative to the planned loading time. This demonstrates the successful implementation of the preventive maintenance system, which minimizes operational disturbances on the laser marking machine.

Table 1. The AV calculation results for each month

Month	Loading time	Operating time	AV (%)
Jan.	728	721	99.03
Feb	699	691	98.85
Mar	637	632	99.21
Apr	595	588	98.82
May	658	653	99.24
June	720	712	98.88
July	569	560	98.41
Aug	704	699	99.28
Sep	731	724	99.04
Oct	740	731	98.78
Nov	715	709	99.16
Dec	716	707	98.74

3.2 PE analysis

PE reflects the machine's ability to produce products within its ideal capacity. The analysis showed that the PE value fluctuated significantly during the observation period, with a range between 59.13% and 93.27% (Table 2). The highest PE value was achieved in April (93.27%), indicating optimal machine capacity use. However, lower performance in other months suggests potential to improve operational efficiency by optimizing production parameters and adjusting machine speeds.

Table 2. The PE calculation results for each month

Month	Product amount	Tact time	Operating time	PE (%)
Jan	450	0.5	721	62.45
Feb	456	0.5	690	66.03
Mar	478	0.5	631	75.69
Apr	548	0.5	587	93.27
May	437	0.5	652	66.97
June	436	0.5	711	61.27
July	453	0.5	559	80.96
Aug	467	0.5	698	66.85
Sep	434	0.5	723	59.98
Oct	432	0.5	730	59.13
Nov	435	0.5	708	61.39
Dec	475	0.5	706	67.23

The fluctuation in PE throughout the year suggests inconsistent use of the machine's production capacity. Several factors may contribute to this variability, including irregularities in the raw material supply, operator performance, minor stoppages, and non-standardized operating procedures. Months with lower PE values, such as October (59.13%) and September (59.98%), likely experienced disruptions that hindered the machine from operating at its full potential, such as frequent adjustments, prolonged setup times, or suboptimal scheduling.

To improve PE, it is crucial to conduct a root cause analysis of performance losses and implement targeted corrective actions. Standardizing work instructions, enhancing operator training, and implementing real-time monitoring systems can help reduce cycle time variability and eliminate unnecessary delays. Additionally, integrating TPM principles (particularly focused improvement and autonomous maintenance) can address hidden inefficiencies and improve performance stability. Monitoring PE trends over time also enables management to identify best practices during high-performance months (e.g., April) and replicate them across other periods to achieve consistent and optimal productivity.

3.3 RQ analysis

The quality rate describes the machine's ability to produce products that meet quality standards. The calculation results show that the RQ value ranges from 84.10% to 93.56% with an average of 89.21% (Table 3). The highest RQ value was achieved in November (93.56%), while the lowest was in July (84.10%). The lowest value occurred in July (84.10%). Fluctuations in the RQ value indicate variability in the production process that affects the quality of output. Stricter implementation of quality control and root-cause analysis of production defects can improve consistency in quality.

Table 3. The results of the RQ calculation for each month

Month	Number of units processed	Defect total	RQ (%)
Jan	450	30	93.33
Feb	456	61	86.62
Mar	478	56	88.28
Apr	548	44	91.97
May	437	59	86.49
June	436	65	85.09
July	453	72	84.10
Aug	467	45	90.36
Sep	434	45	89.63
Oct	432	37	91.43
Nov	435	28	93.56
Dec	475	49	89.68

The variation in the RQ across the observed months suggests recurring issues in the production process that affect product conformity. Factors such as inconsistent raw material quality, operator errors, improper machine calibration, or inadequate inspection procedures could be contributing to these fluctuations. To address this, implementing stricter in-process quality checks, enhancing operator training on quality standards, and using Statistical Process Control (SPC) tools can help detect and reduce defects earlier in the production line. By identifying and addressing the root causes of defects, companies can improve not only product quality but also customer satisfaction and overall production efficiency.

3.4 OEE analysis

OEE is a comprehensive indicator that combines the previous three parameters (AV, PE, and RQ). The results of OEE calculations during the observation period showed values varying from 51.56% to 84.77% (Table 4). The highest OEE was achieved in April (84.77%), while the lowest was in June (51.56%). According to the JIPM standard, the ideal OEE value is above 85%. Although the OEE value in April was close to the perfect standard, there is still room for improvement in the other months.

Table 4. Shows the results of the OEE calculation for each month

Month	AV (%)	PE (%)	RQ (%)	OEE (%)
Jan	99.03	62.45	93.33	57.71
Feb	98.85	66.03	86.62	56.54
Mar	99.21	75.69	88.28	66.30
Apr	98.82	93.27	91.97	84.77
May	99.24	66.97	86.49	57.49
June	98.88	61.27	85.09	51.56
July	98.41	80.96	84.10	67.01
Aug	99.28	66.85	90.36	59.98
Sep	99.04	59.98	89.63	53.25
Oct	98.78	59.13	91.43	53.41
Nov	99.16	61.39	93.56	56.96
Dec	98.74	67.23	89.68	59.53

Further analysis showed that the main factor affecting OEE was PE, which exhibited high variability throughout the observation period. Optimizing production parameters and adjusting machine speed are priority areas for improvement.

The consistently high AV values and the relatively stable quality rate (RQ) suggest that the preventive maintenance program and quality assurance practices are generally effective. However, significant variation in PE directly impacts OEE, as even small inefficiencies in machine speed or idle time can substantially reduce overall effectiveness. This highlights the importance of focusing improvement efforts on production flow optimization, such as reducing minor stoppages, improving line balancing, and ensuring that machine operators follow standardized operating procedures. By addressing these performance-related issues, the company can work toward achieving a more consistent, higher OEE, moving closer to the JIPM benchmark.

3.4.1 Monthly OEE trend

This subsection presents the trend in OEE for the laser marking machine over 12 months. The data illustrate the baseline performance before TPM intervention and the subsequent improvement following the implementation of focused maintenance strategies. The trend analysis is essential to evaluate whether the TPM program (particularly the focused improvement and autonomous maintenance pillars) had a measurable impact on the machine's performance, availability, and quality rates over time. Fig. 2 shows the monthly OEE progression and highlights the period during which significant improvement actions were implemented.

Fig. 2. OEE trend of the packaging machine

3.4.2 Six significant losses Pareto

To identify the root causes of OEE inefficiencies, a Pareto analysis was conducted based on the six significant losses framework. This framework categorizes productivity losses into six distinct areas: equipment failure, setup and adjustment, idling and minor stoppages, reduced speed, process defects, and reduced yield. The purpose of this analysis is to determine which loss categories contributed most significantly to the reduced OEE, thus guiding targeted improvement strategies. Fig. 3 Visualizes the proportional contribution of each loss type, allowing for prioritization of remedial actions in future maintenance planning.

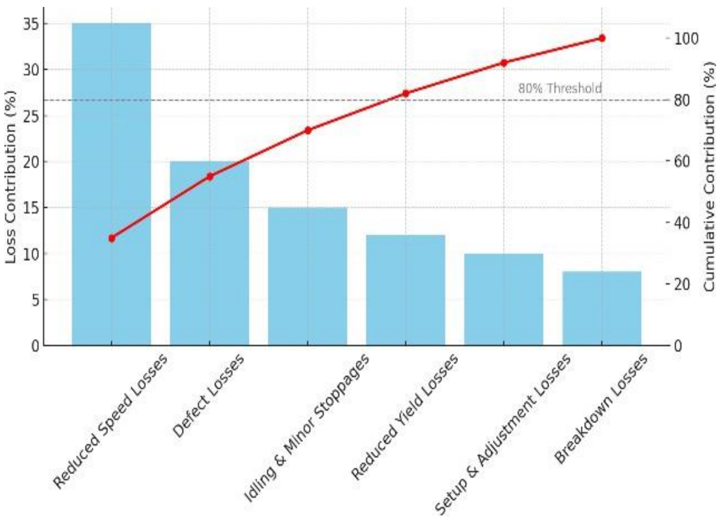

Fig. 3. TPM pillar contribution to the machine

The analysis of the six significant losses reveals that performance losses are the dominant contributor to overall equipment inefficiency, accounting for 38% of the total OEE loss. This pattern indicates a recurring operational risk, primarily linked to minor stoppages and speed reduction on the laser marking machine. Such inefficiencies pose profound implications, including reduced production output, line imbalance, and potential downstream disruptions. Left unresolved, these risks can compromise the continuity and reliability of packaging operations.

The implementation of focused improvement activities effectively addressed these risks by targeting the root causes of minor stoppages. For instance, regular sensor alignment adjustments and fine-tuning of the conveyor speed resulted in a visible reduction in unplanned micro-downtime events. In parallel, autonomous maintenance empowered operators to detect early signs of equipment deterioration, contributing to quality stability. These findings confirm that TPM not only improves equipment effectiveness but also serves as a strategic tool for mitigating operational risks.

3.5 Maintenance management

The maintenance program combined scheduled preventive maintenance with TPM principles to create a proactive culture emphasizing routine cleaning, sensor checks and calibration, lubrication, and timely component replacement. Autonomous maintenance enabled operators to detect early abnormalities and monitor performance, reducing minor stoppages and enhancing reliability without significant capital outlays. At the same time, Computer-Based Maintenance Management Software (CMMS) supports improved record- keeping and decision- making. This included regular inspections, cleaning, lubrication, and timely replacement of worn-out components. In parallel, TPM principles were adopted to directly involve operators in basic maintenance activities, such as early detection of abnormalities and performance monitoring, thereby reducing minor stoppages and improving equipment reliability. The integration of these two approaches created a proactive maintenance culture that not only enhanced machine availability but also improved OEE throughout the observation period.

3.5.1 Preventive maintenance

Preventive maintenance is performed to prevent damage before it occurs. Preventive maintenance activities include the following: (1) Routine cleaning of the machine components, (2) checking and calibration of the sensors, and (3) replacement of components that have.

This maintenance is carried out based on a predetermined schedule and the machine manufacturer's recommendations. The consistent implementation of preventive maintenance has contributed to the Laser Marking machine's high AV during the observation period.

3.5.2 Corrective maintenance

Corrective maintenance is performed after damage or interference with the machine occurs. The main objective of corrective maintenance is to restore the machine to normal operational conditions as quickly as possible, minimizing production downtime.

A sound monitoring system, including machine condition data, maintenance records, and defect analysis, enables the maintenance team to identify problems early and take necessary preventive measures. Using CMMS can simplify maintenance management. Maintenance by providing more organized and structured information.

The documented gains illustrate that even a single bottleneck machine can deliver double-digit OEE improvements when TPM pillars are selectively prioritized. Plant managers can replicate the roadmap to capture similar benefits without significant capital outlays, starting by eliminating micro stoppages and upgrading operator skills.

4 Conclusions

This study demonstrates that over 12 months, the availability remained consistently high due to effective preventive maintenance averaging 98.95%, while significant variability in performance efficiency constrained overall OEE despite relatively stable quality rates. The OEE peak of 84.77% indicated good performance, but the average of 60.38% highlighted the need for persistent, structured improvements, especially on performance losses driven by minor stoppages and speed reductions. Focused improvement and autonomous maintenance were effective in mitigating these risks. The study also found that critical operational risks particularly minor stoppages and speed losses materially reduced equipment effectiveness. Applying TPM, especially the focused improvement and autonomous maintenance pillars, mitigated these risks by addressing systemic inefficiencies and empowering frontline operators. By adopting a long-term, risk-based evaluation framework, the research yields deeper insight into recurring losses and offers practical, data-driven recommendations for maintenance planning. Collectively, these actions strengthen line reliability and provide a structured basis for sustaining OEE gains over time. This study is limited to single production line therefore future research should extend this model to multi-lined systems and incorporate predictive maintenance technologies to anticipate quality drift and reduce downtime risk in real time.

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